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INTERORGANISMIC AND ENVIRONMENTAL INFLUENCES THROUGH EXTREMELY WEAK ELECTROMAGNETIC FIELDS [1]

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A large amount of evidence has accrued over the past decade that organisms are not only sensitive to electromagnetic fields as weak as the earth's natural ones (Dijkgraaf and Kalmijn, 1963; Brown, Park, and Zeno, 1966; Lindauer and Martin, 1968; Keeton, 1971; Brown, 1971; Wiltschko and Wiltschko, 1972; Rommel and McCleave, 1972; and many others) but that their rates of metabolism or of "spontaneous" activity may reflect natural fluctuations in electromagnetic fields of the atmosphere. These fluctuations may be correlated with weather system movements (Truchan and Boyer, 1972) and times within the major geophysical cycles (Brown, 1962a, 1962b, 1963, 1965, 1968; Stutz, 1971). Indeed, Cumming (1967) has reported correlations between seed germination and solar radio flux. Others have reported annual variations in seed germination in presumed constant conditions (Bünning and Müssle, 1951; Bünning and Bauer, 1952).

In the course of search for the consequently expected differences in biological phenomena resulting from conducting observations at different sites in a modern laboratory with its greatly and diversely disturbed ambient weak electromagnetic fields, and concurrently at two geographic sites 1000 miles apart, such differences soon became clearly apparent. However, an additional and quite unexpected discovery was made that electromagnetic contributions to the environment by some organisms themselves can lead to an altered behavior of others nearby. The presence of this latter phenomenon and the gradual disclosure of some of its remarkable characteristics as the investigation progressed compelled on a number of occasions diversion from initially planned experimental objectives.

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Methods, Experiments and Results

Preliminary studies

To assay biological differences at positions with obviously different electromagnetic fields the rate of water uptake by certified pinto beans *Phaseolus vulgaris*, (University of Idaho #111) first was chosen. From a 50 lb bag beans were used without any selection other than discarding broken ones or the very occasional, odd, extremely small specimens. This seemed to offer opportunity for simple, precise measurement of a reaction rate from a fixed constant starting point. The mean rate of water uptake during an accurately timed 4-hour period following submergence of 10- or 20-bean samples in shallow 6×6 cm square aluminum-screen trays in water could be readily determined.

Water uptake was determined as the difference between initial and final wet weights and then expressed as the percentage of initial dry weight. The flat, low trays with their single bean layer were designed expressly for quick, uniform blotting on absorbent tissue followed by fast weighing on torsion balances. The trays weighed 115 ± 1 centigrams. The first few hundred initial wet weights indicated that 9 to 22 centigrams became added when the beans were wet. These added values showed what appeared to be essentially a normal frequency distribution about a mode close to 15 centigrams. Subsequently, for the wet weight 15 centigrams was routinely added to dry weight of beans and tray to obtain the initial wet-weight value. The errors of measurement were hence all relatively small in relation to the 4-hour, 150–700 centigram water uptake by the beans and contained no systematic error.

The dry weight of the samples characteristically fell at a value between 7.5 and 9 grams and was recorded to the nearest centigram. The water uptake in four hours at room temperature during studies between February 22 and December 1, 1972 ranged from about 18% to more than 80% for 20-bean samples despite the air-conditioned, temperature regulated ($22 \pm 1.5°$ C) laboratory environment. With two exceptions which will be indicated later, all experiments were performed in a groundfloor laboratory suite of Hogan Biological Laboratory, Evanston, Illinois.

In an initial experiment trays of 20 beans were placed in 10 cm glass finger bowls at two sites in the laboratory. Two were juxtaposed on a wooden table top near the center of a room, a position discovered to be as undisturbed in its magnetic-field strength and orientation as any to be found in the laboratory. Another two finger bowls were juxtaposed on a stone chemical bench about 25 cm from a steel utility column at the surface of which a magnetic field of about 1½ oersteds was measurable. Observations were made at these sites generally both morning and afternoon five days a week from February 22, through April 14, 1972.

Although an expected positive correlation ($r = +0.323$, $t = 2.97$, $n = 78$, $P < 0.005$) was found between the concurrent mean values obtained day by day from the two sites located in different rooms and separated by about 50 ft in the laboratory suite (Fig. 1) it was surprising to discover that no significant correlation existed between the two parallel bean samples closely side by side at each site, where it had been anticipated that the correlation would have been highest.

In an attempt to account for this latter absence of correlation, the "structure" of the relationship between the members of the pairs for the pooled data from the

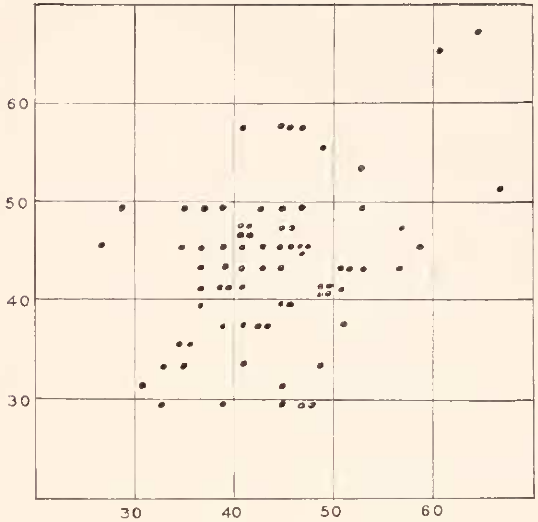

FIGURE 1. Scatterplot of the relationship between the mean water uptake for pairs of 20 bean samples with one pair of juxtaposed vessels located at a magnetically "disturbed" laboratory site (abscissa), and a second, similarly closely apposed, pair about 50 feet away at a "quiet" site (ordinate).

two sites was examined (Fig. 2A). For the scatterplots, with the 20-bean samples the data were grouped into 2% classes, and for the 10-bean ones treated below, into 3% classes.

There was a clear suggestion from inspection of Figure 2A that the values did not comprise a simple homogeneous population; there appeared to be a mixture of two populations, one with smaller variance and a negative correlation and the other with greater variance and displaying a positive correlation. To understand what could be the basis of such a mixture we must consider the significances of the correlations themselves. Being related are the varying values obtained from one sample of beans (abscissa) and the values simultaneously being derived from another (ordinate). Were these two samples fluctuating fully randomly and independently from one sampling period to another, a random distribution of points in the scatterplots would be evident, there would be no statistically significant correlation, and one might expect each, the ordinate and abscissa values, to display a normal distribution.

The hypothesis underlying the present investigation was that the varying values from one sampling period to another were not fully randomly distributed, and the differences reflected to a statistically significant degree the responses of the beans to concurrent variations in subtle, pervasive factors of the atmospheric environment which were postulated to be electromagnetic. Since all atmospheric parameters, whether subtle or obvious, are well-known not to exhibit a random day to day fluctuation or even to possess a normal distribution of their values (*e.g.*, atmospheric temperature or pressure), any variation of the bean water uptake would, to the extent it constituted an environmental response, comparably deviate from normality.

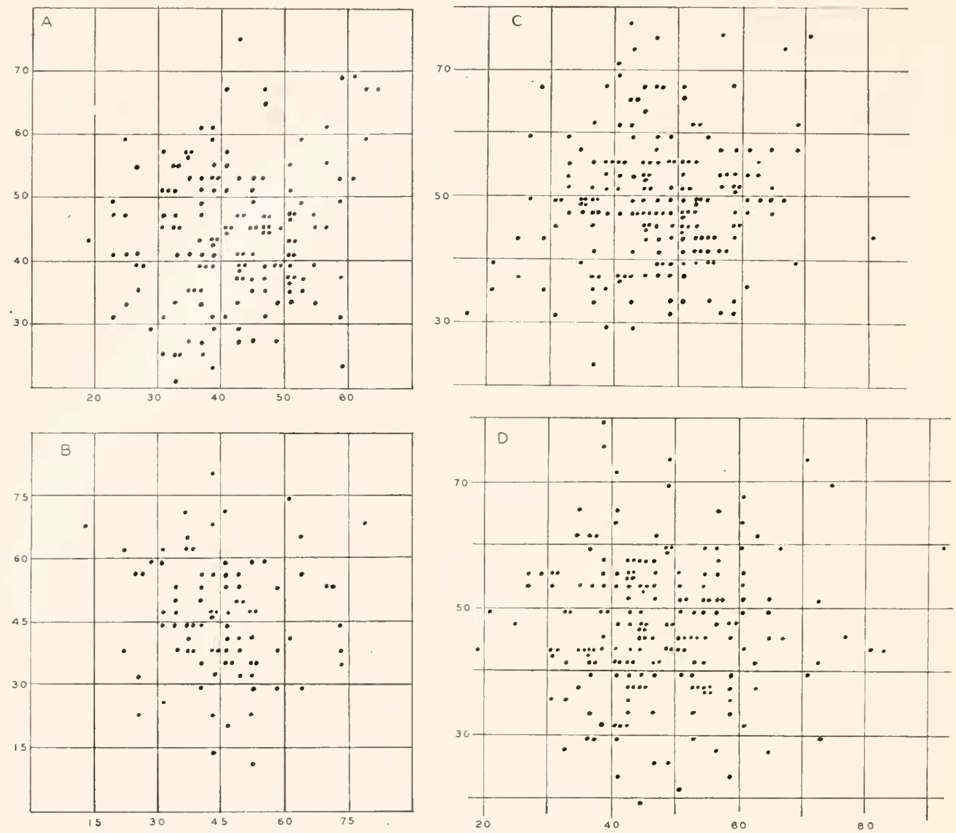

FIGURE 2. Scatterplots between rates of water uptake in paired samples of beans; (A) between the two members of the pairs of Figure 1; (B) between members of closely apposed vessels each containing 10 beans; (C) between 20-bean samples in trays about 35 cm apart (see text); (D) between members of paired 20-bean samples in the weak field of a slowly (2 rpm) clockwise rotating horizontal bar magnet.

The hypothesis that the beans continue to exhibit responses to ambient environmental variations even under conditions of controlled constancy of all obvious ones would, most simply, predict the beans to display a positive correlation between two independent samples investigated concurrently in the same environment. This would result from parallel environmental influences. If this were the case, a statistically significant positive correlation would be expected and the scatterplots should reveal upon inspection evidence for a homogeneity of such character that not only the total mass of points but any and every substantial assemblage of points arbitrarily delimited by boundaries parallel to the ordinate or abscissa coordinates should reflect the positive character of the relationship.

There was an alternative possibility which our hypothesis included, and which had been suggested in many data obtained over many years, namely that the correlations of a biological system with subtle ambient field-variations could be either positive or negative. Environmentally dependent temporal patterns of variation of two independent biological samples held under different environmental conditions, could conceivably mirror-image one another and a negative correlation exist between them. In the beans investigated concurrently and under the same experimental conditions there could theoretically be for two independent samples day to day parallel fluctuations in sign between positive and negative. Under these circumstances there would be expected only a reinforced positive correlation between two concurrent samples but no expected inhomogeneity in scatterplots. The occurrence of such inversions parallelly for both samples would hence probably not be readily identifiable.

Another possibility existed, namely that little or no correlation would exist between two concurrently studied samples as a consequence of a random and independent distribution of correlating signs of response of the two biological samples to their common environmental fluctuations. In this case the correlation coefficient could conceivably be even zero while two populations of values might be conspicuously evident upon inspection of the scatterplots as an X-formed distribution of values. One population of values could be clearly contributing a negative correlation, the other a positive one.

Our hypothesis, however, had not taken into account the additional possibility that was clearly suggested by the relationship between the two samples illustrated in Figure 2A, namely two populations of points in which a negatively correlating one was not counterbalanced over the same range of values by an equal and opposite positively correlating population of values. The only possibility for the explanation of such a relationship was the existence of a mutual interaction between the two samples that had been hitherto presumed to be behaving independently of one another. The relatively large range of values over which the uncompensated negative correlation occurred suggested that the influence of the interaction was substantial. The simplest hypothesis for the nature of the interactional influence seemed to be that the two samples in some manner biased one another to adopt opposite signs for their correlated responses to the varying subtle geophysical parameters which were effecting the day to day fluctuations in water uptake.

The specific character of the two populations of Figure 2A suggested an *ad hoc* means for confirming existence of its peculiar population admixture. This was qualitatively accomplished through learning that for those correlated values that lay within the range of 32% up to 58% the coefficient of correlation, r, was -0.32, $n = 99$, and for all those values that lay beyond this range $r = +0.33$, $n = 57$. Correlations of this magnitude and with such sign differences are definitely not expected in homogeneous populations of truly random, or even correlated, data which are extracted from scatterplots in this specific manner. These correlations certainly suggest trends but are perhaps questionably accessible to rigorous determination of probabilities.

In view of the uniformity of the beans used, the positive component of Figure 2A was expected from commonly reported general correlation between rates of biological activities and fluctuating subtle parameters, including electromagnetic, of the atmosphere. The negative correlation, spanning from about 70% to 126% of mean rate of water-uptake for that period was, on the contrary, quite unexpected.

Comparing the extent of the negative correlation for the two sites separately, the "undisturbed" location yielded a value of $r = -0.42$, $n = 51$, while the "disturbed" area gave also a negative, but much smaller $r = -0.18$, $n = 48$.

Another series of "paired" experiments was also being conducted both mornings and afternoons commencing on February 22, similarly on the stone-topped chemical bench, but no closer than 75 cm to the service column. In this series the bean samples included only 10 seeds. Again, two pairs of vessels were used; these were separated by only about 50 cm. There were two initial objectives for this series, (a) to learn whether 10-bean samples would provide results quite comparable to those of 20-bean ones and (b) to determine the magnitude of an expected correlation between two pairs only 50 cm apart when they were, therefore, in essentially the same specific laboratory environment. The variances observed among the smaller sized samples were found to be greater than for 20-bean ones. Correlation between the two members of the pairs was also statistically insignificant (Fig. 2B), but as for the 20-bean series a population inhomogeneity was evident upon inspection of the scatterplot; over an intermediate range of values of 28% to 62% a negative value of $r = -0.27$, $n = 59$, was obtained.

Another experiment was performed. This one was initially designed to determine whether differences in strength of ionizing radiation would effect differences in rate of water uptake and if so, whether the influence might differ between when the field was administered parallel and at right angles to the earth's horizontal magnetic vector as had earlier been disclosed for an influence on light response for *Dugesia* (Brown, 1963, 1971).

Between March 6 and April 14, 1972, at a relatively "undisturbed" position in the laboratory, five trays of 20 beans each were placed in a large 33-cm long rectangular plastic vessel and aligned close together in a row toward magnetic north from a weak (24 μCi) gamma source yielding a gradient along the five samples ranging from $17 \times$ background for the closest to $2.5 \times$ for the most distant. A completely comparable series of 20-bean trays was arranged in exactly the same manner in a second large plastic vessel, but directed from the same gamma source toward "magnetic west." For both series, the closest tray was numbered 1, and the most distant, 5. From center to center of the closest bean groups between the two vessels was 15 cm. Correlating percentage water uptake between samples in the two series, N and W, relating them in the reversed order in the gamma radiation gradient (*i.e.*, $1^N \times 5^W$, $2^N \times 4^W$, *etc.*), in order to minimize any possible existent contributions by the gamma-field gradient itself, yielded r as a positive but statistically insignificant $+0.146$, $t = 1.82$, $n = 150$. However, a comparable correlation in a sequence paralleling the gradient (*i.e.*, $1^N \times 1^W$, $2^N \times 2^W$, *etc.*) gave r as a statistically significant $+0.2845 \pm 0.075$, $n = 150$, $P < 0.001$.

Examining the structure of the correlation scatterplot for the reverse-related samples it was noted, now for the third time, that an inhomogeneity in the population existed. This too appeared to result from a mixture of two populations. One sizable population of values which exhibited a negative correlation was responsible in good measure for the relatively small value of r that had been obtained. The substantial magnitude of this negative contribution was indicated by finding that over the range of values from 38% to 56% (Fig. 2C), values spanning the mean, $r = -0.41$, $n = 78$. The negatively correlating population of values was apparently slightly more restricted in its range under these experimental conditions than under the conditions for the two previous cases.

In the direct serial order correlation this negatively correlating population of values seemed reduced and largely overridden by a relatively strong positively correlating relationship between 4N and 4W, and 5N and 5W, which were the groups most distant from one another, about 43 and 53 cm, respectively. In the "reverse-correlated" study the interdistances ranged around, and close to, 35 cm between all correlated samples.

To learn whether a fluctuating, weak magnetic field might modify rate of water uptake another experimental series was conducted concurrently with the gamma-field one, trays of 20-bean samples were placed in two tandemly arranged 33 cm long plastic containers, each with three trays with all six trays lined up about one tray-width apart to "magnetic east" from a rotating horizontal 18 cm bar magnet, turning clockwise (viewed from above) 2 rpm. The magnet provided at about 46 cm a horizontal field strength equal to the ambient horizontal one at that site in the laboratory. Correlating the first tray of beans in the first container with the first in the second, the second with the second, *etc.,* r was very close to zero. A repetition of the experiment was performed with eight trays of beans in a line of four pairs of 10 cm finger bowls with one juxtaposed pair as close to the rotating magnet as feasible and the remaining pairs at 74 cm intervals away. No significant correlation existed when #1 was related to #3, 2 to 4, 5 to 7, and 6 to 8. Nor was any correlation evident when #1 was related to #2, #3 to #4, etc. The pooled results of these two rotating magnet series gave $r = -0.03$. However, an examination of the structure of the relationship between the samples suggested, from both kinds of series separately, that we were probably here, too, not dealing with randomly varying data. A "figure X" tendency in the scatterplots between the correlated samples suggested that we had, instead, biological systems that were correlating both + and −, with close to equal frequency.

A third study, in the field of the rotating magnet, with a geometric and geographic arrangement exactly as for the gamma study, was also performed. Correlating in "reverse sequence" to minimize any graded contribution resulting from effect of magnetic field strength itself, an "X" tendency in the scatterplot was again suggested, and r was again very close to zero. The pooled results of all three rotating-magnet series are illustrated in Figure 2D. Although here again, two populations of values were suggested, they seemed about equally divided between + and − correlating groups.

With the initial intention of assuring that both members of paired samples of beans would be occupying the same space at essentially the same time and hence any negatively correlating relationship such as those noted earlier could not be ascribed to subtle differences between two fixed locations, another kind of observation was made. Two pairs of trays of 10 beans each, in 10 cm finger bowls, were placed on a counterclockwise (from above) rotating platform, 6 rpm. Two bowls were placed in contact with one another on each side of the axis of rotation. The bean trays in the paired bowls averaged about 10 cm from center to center. The distance of the second pair from the first averaged about 19 cm with the distance between centers of the diagonally opposing bean-trays being about 24 cm. Observations were made of water uptake over 21 half days spanning about two weeks

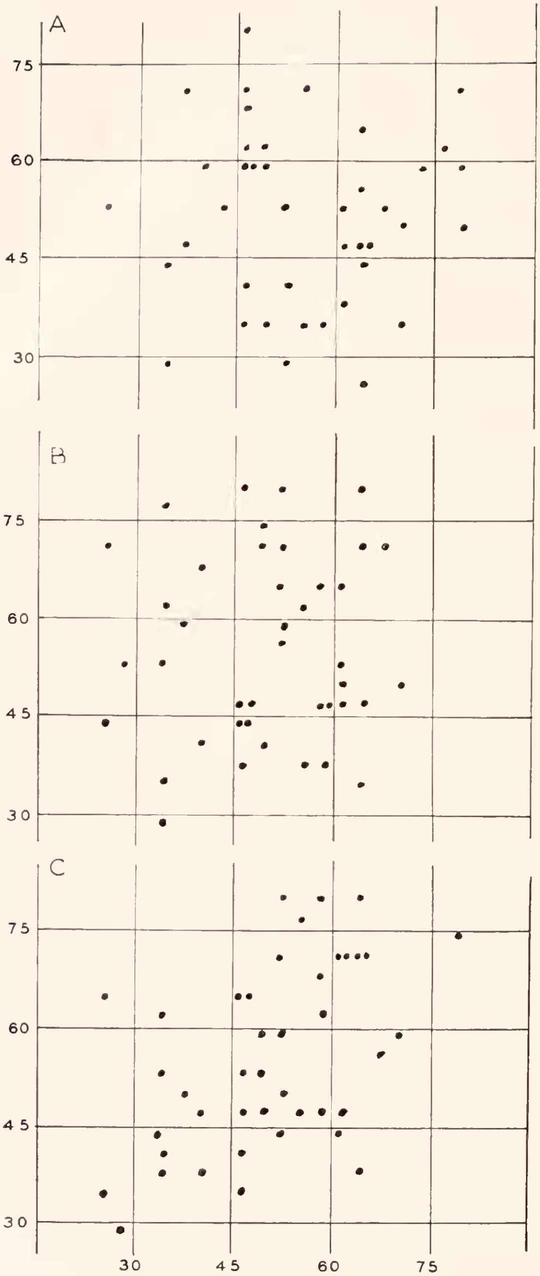

FIGURE 3. Scatterplots between 10-bean samples in four separate vessels on a 6 rpm, counterclockwise rotating platform with two pairs symmetrically paralleling one another 9.5 cm on opposite sides of the center of rotation; (A) between members of pairs; (B) between directly opposite counterparts; (C) between diagonally opposite counterparts.

(April 10–24, 1972). No significant correlations were present either between the two members of the paired samples (Fig. 3A), or between the corresponding tray of the opposite pair (Fig. 3B). However, strikingly, a good, highly significant positive correlation was discovered between the diagonally opposite samples (Fig. 3C), $r = +0.483$, $t = 3.49$, $n = 42$, $P < 0.002$.

A final preliminary study was commenced to learn whether perhaps the negatively correlating element that had been noted between the two members of closely apposed paired groups perhaps depended upon sample proximity itself and would disappear if members of the correlated pairs were separated by more than the 43 to 53 cm distance that the gamma series suggested no longer to be contributing to the negatively correlating central population within the scatterplot. Twelve 10 cm finger bowls, each with a tray of 20 beans, were arranged as three groups of four, each group on a separate table, in the following manner in a relatively "undisturbed" area of the laboratory. In each group were two closely apposed to one another to comprise a "pair." The other two in each group were separated by a distance of 70 cm from the "pair" and more than this from one another, or from beans of any other group. On the basis of a possible influence of sample proximity either no correlation, or a low positive one, over the central range where bean "interactions" appeared to have been displayed was predicted when the two "singles" were correlated. A low positive one could result from a parallel response to their common physical environment. In short, the sign of each sample might be, independently, + or − without being biased by any adjacent bean sample. For the paired samples, on the other hand, a negative correlation would be expected for this central range as one group biased toward opposite sign the adoption of the sign by the other.

The results from 20 half-day experiments from April 24 through May 5, 1972, disclosed that within the same central range of values, 38% up to 58% (Fig. 4B), the paired samples yielded, as predicted if biasing existed, a negative correlation, $r = -0.361$, $n = 31$. For the corresponding "singles" for each group (Fig. 4A), on the other hand, a small positive correlation was present, $r = +0.149$, $n = 30$. Each "single" thus appeared to have its sign, whether positive or negative, determined without influence of the other, with a weak suggestion of operation of a varying component in the physical environment influencing them in a parallel manner.

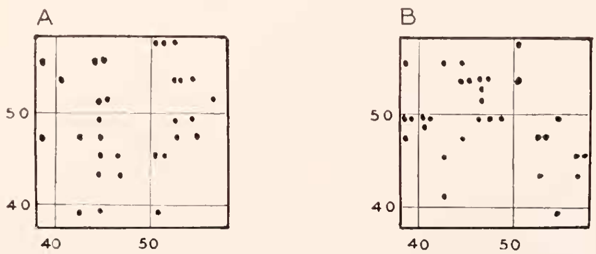

FIGURE 4. Scatterplots of relationships within the range of 38% to 58% of water uptake for (A) two samples separated by more than 70 cm from one another and (B) two samples closely juxtaposed in separate vessels.

"Pairs" vs. "singles"

The precedings "pairs" vs "singles" experiment was continued through August 18, 1972. Assays of water uptake were made both morning and afternoon through June 2, after which only single daily assays were performed. The 10 cm glass finger bowls were replaced by cylindrical, transparent plastic vessels, 9 cm in diameter and 4.5 cm deep. The original certified bean strain was replaced by uncertified pinto beans obtained from a large commercial supplier in Nebraska. The beans were thereafter submerged mornings and their water uptake was determined four hours later, in the afternoons. Figure 5A illustrates the day by day variation in the mean percentage water uptakes, only the afternoon values from May 19 through June 2, and then single daily ones until the end of the study on August 18, 1972, for the "pairs" and "singles" separately. The concurrent two mean values during the whole period of study exhibited a high correlation with one another, $r = +0.806$, $n = 111$. In the same illustration, Figure 5B, are seen the concurrent mean water uptake percentages from June 5 onward for nine 20-bean samples arranged as three triplets of linearly juxtaposed vessels. These last, being investigated in an adjoining room within the laboratory suite to learn in what manner an extra bean sample might influence pair interaction, are noted to be comparably highly correlated in their systematic variation in mean rates with the "singles" and "pairs" in the other series.

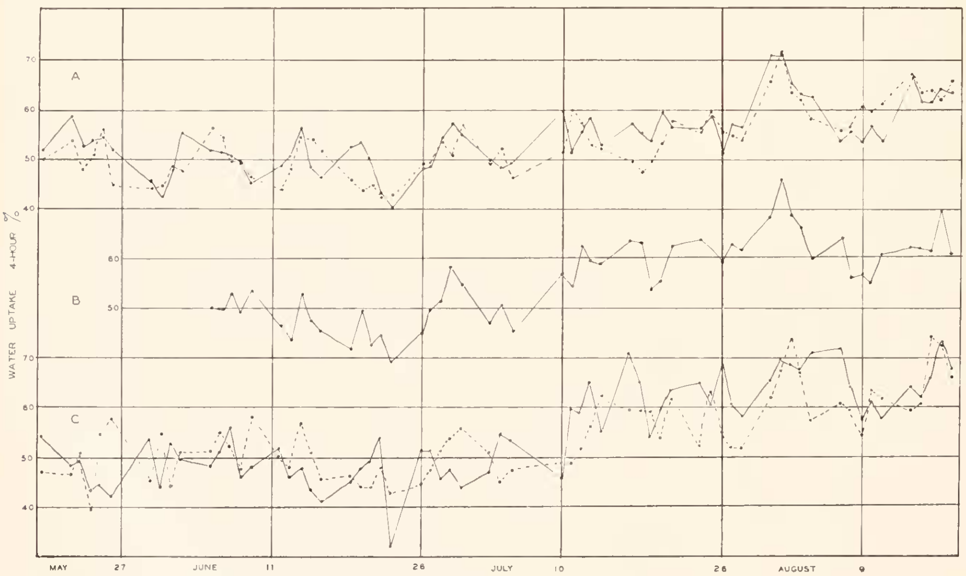

FIGURE 5. Variation from day to day in mean rate of water uptake for (A) (solid line) six 20-bean samples separated by 70 cm from one another, and (broken line) six 20-bean samples arranged on the same three laboratory tables but as closely apposed pairs; (B) nine 20-bean samples arranged as three triplet groups at a second laboratory site bout 40 feet away; (C) (solid line) four 20-bean samples, arranged as two pairs, on a 6 rpm, clockwise rotating platform and (broken line) on a counterclockwise rotating one a short distance away in the same room but a different room from A and B.

In order to abolish the high positive correlation which was a consequence of the conspicuous parallel variation in rate of water uptake in the means for all these bean samples the rate of water uptake in each of the twelve "singles" and "pairs" samples was expressed each day as a deviation from the mean value for all twelve for the concurrent interval. It was recognized that upon simple grounds of probability, a very weak negative correlation would be the null expectation from correlating pairs of these values and therefore statistical significances would depend upon significant differences from appropriate "controls" employing the same population of deviations.

Examination of the correlation scatterplots of the 333 values relating deviations from the daily means for the members of the juxtaposed trays on the one hand, and the pairs of separated trays on the other, revealed a gross difference between them. For the "singles" there was suggested a "figure X" relationship, a relationship not similarly suggested for the closely apposed pairs of trays. The difference is described and quantified in Figure 6. In this figure the variance for one member of a "pair" is plotted against deviation from the mean for the second member for ±4% intervals (the open circles), and the variances of the second member are comparably shown in relation to the deviations of the first (solid circles). The numbers contributing to each point are indicated. For the "singles" (Fig. 6A) it is evident that variance of one member systematically increases with deviation of the other from the mean, a relationship consistent with the apparent "figure X"

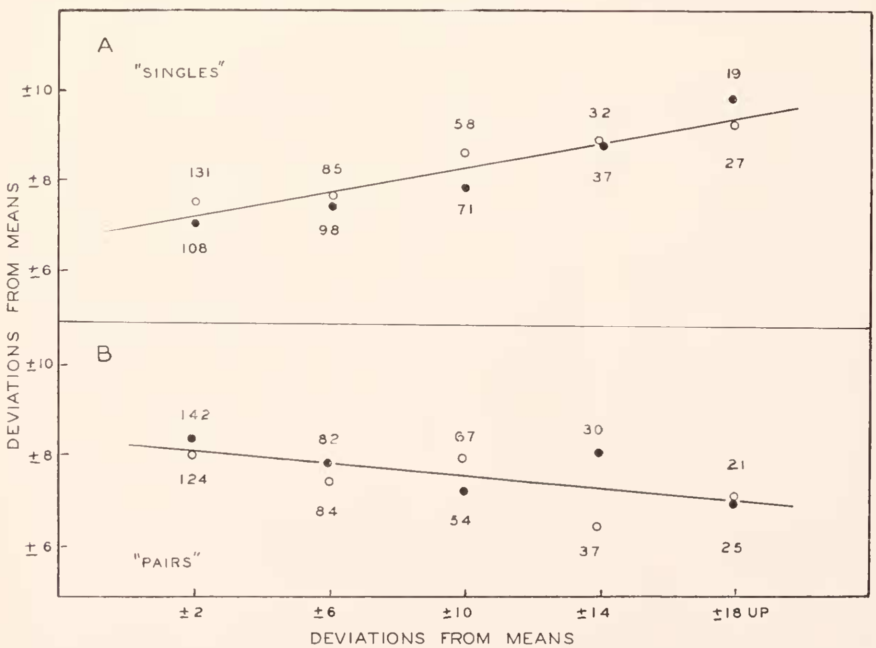

Figure 6. The relationship between (A) (circles) the deviation from the mean, without sign, for one of the two correlated "singles" and the concurrent comparable deviation for the second, and (dots) vice versa. (B) The same for the two correlated "pairs."

relationship in which both positively and negatively correlating relationships between the samples appeared to occur with about equal frequency.

When, on the other hand, the members of the closely apposed paired samples were analyzed in an entirely comparable manner the relationship seen in Figure 6B was obtained. Now the *greatest* variance in one is noted for the *smallest* mean deviations of the other, the variances of one *decreasing* systematically as the mean deviations of the other *increase*. In other words, when the value of one member of the pair is near the mean value for that day, the other member is biased away from that mean, and when one member, instead, deviates farther from the mean, the other member is permitted to approach more closely the mean for the day. Indeed, even more, when one member of a pair deviates far from the mean, the other member of that pair appears to be prevented from deviating far, whether in the same or opposite direction.

The preliminary observations of the presence near their means of a negative correlation between members of closely apposed bean samples is, therefore, supported by these additional results. Separation of the members of the pairs by about 70 cm appears to have prevented this interaction thereby permitting each member of the pair to become, independently of the other, positively or negatively correlated with whatever is the effective subtle geophysical factor of factors.

Rotating platforms

The preliminary experiment involving the two pairs of 10-bean samples on a rotating platform at 6 rpm CCW (counterclockwise) was continued, but altered to 20-bean samples and amplified by conducting simultaneously, and nearby in the same small laboratory room, an entirely parallel series differing only in that the rotation of the platform was CW (clockwise). The experiment commenced April 25 and terminated on August 18, 1972. The series were run both mornings and afternoons through June 2 and thereafter only once each day, over the noon period. Plastic vessels were substituted for the glass ones.

The day to day variations in mean water uptake for the two series are shown independently in Figure 5C only for afternoons through June 2 and thereafter daily through August 18. Inspection of this illustration clearly indicates that for the gross trends there is a positive correlation between the means of the four samples on the CW and the CCW rotating platforms. Suggested, however, is the common occurrence of apparent inversions between them for a single days or over a series of several days.

When the nature of any correlations between the individuals of pairs and between diagonally related trays for the two platforms were investigated it became quickly evident that the CW and CCW rotations were clearly not equivalent. Because of the longer-term parallel trends, statistically significant positive correlations were found between members of the pairs and of the diagonals for both rotational directions. However, some statistically highly significant differences were noted among them.

The lowest correlation $r = +0.195 \pm 0.066$ was found between CCW pairs with a higher one, $r = +0.262 \pm 0.064$, for the diagonals. Next in degree of correlations were the diagonals for the CW rotating samples with $r = +0.401 \pm 0.058$. Highest was the correlation between members of the CW pairs, with

$r = +0.477 \pm 0.053$. For each one $N = 220$; the statistical significances are high. Converting r to z the above values became, respectively $+0.195 \pm 0.068$, $+0.266 \pm 0.068$, $+0.420 \pm 0.068$, and $+0.520 \pm 0.068$. The difference between the above CW and CCW pairs was 3.40 times its error ($P < 0.001$). The difference between CW pairs and CCW diagonals was 2.68 times ($P < 0.01$), and between the CW diagonals and CCW pairs, 2.35 times its error ($P < 0.02$). The mean difference between both CW correlations and both CCW ones was 3.36 times its error ($P < 0.001$).

Both inspection of the scatterplots and the particular order of the degrees of correlations suggested that for the CCW rotation, as noted in the preliminary studies, the "pairs" contained a greater negatively correlating element than did the "diagonals." On the other hand, for the CW rotation the diagonals appeared to include more negatively correlating elements than did the pairs. At the same time, CW rotation, relative to CCW rotation, appeared to reduce the degree of that interaction between the bean trays which resulted in the varying degrees of reduction in a fundamentally positive correlation.

Of some interest was whether, perchance, the rotational consequences that were being disclosed might be related in any manner to the effects of extremely slow rotation (1 revolution per day) on plant growth, turgidity, and twining described by Jones (1960). Jones had reported that relative to concurrent plant-growth-rate on stationary platforms the slow CW rotation depressed rate and CCW rotation accelerated it. A comparable influence by very slowly rotating (2 revolutions per day) weak magnets on plant growth rate was reported by Edmiston (1972).

To determine whether the bean water-uptake rate might also be influenced by such slow rotation rates, pairs of vessels containing 20-bean samples were placed on duplicate platforms, arranged side by side, in a light-controlled room at the Marine Biological Laboratory, Woods Hole, Massachusetts. The two pairs were placed on opposite sides, and 30 cm from, the platform center. One platform rotated CW at the rate of 1 rpd, the other was kept stationary. The pairs of bean trays on the rotating platform turned, obviously, through an angle of only 60° in the course of a four-hour run. The experiment continued from June 22 through August 18. In view of the great change in rate of water uptake that was occurring over the course of this 2-month period in all experimental samples (see Fig. 9A) the data were converted daily to deviations from the mean for all of 28 bean samples that were involved in the several experiments proceeding concurrently in the same room.

Correlating members of pairs on the CW rotating platform (1 rpd), $r = -0.129$; $n = 84$, and on the static one, $r = +0.230$; $n = 84$. Transforming r to z the difference between those two was statistically significant, $P < 0.03$.

Lead covers and electrical shielding

Other experimental series led to further interesting observations and conclusions. The possible influences on water uptake by (1) attenuation of the ambient electrostatic field, especially any vertical component, and (2) augmentation of any vertical component of background radiation through the "Rossi effect" of production of cosmic ray showers through the super-imposition of lead plates, were investigated.

Four pairs of 12-cm square glass vessels were arranged on a large wooden table as 4 juxtaposed pairs (12 cm, center to center). Two of the pairs, separated by 24 cm, were to be involved in the electrical shielding experiment. The other two pairs, separated by 34 cm, were for the lead-cover one.

The specific environment of the laboratory site where these experimental setups were located was very clearly one of the more electromagnetically "disturbed" areas of the laboratory. There was virtually no horizontal vector of magnetism over portions of the table area and over the remainder the needle of a very sensitive surveyor's compass often drifted slowly and erratically to various geographic directions. This highly disturbed state of the ambient magnetic field at this specific location appeared due to the presence of heavy electrical building-service equipment in the basement directly below.

The electrical field was attenuated for one of the pairs of bean-samples by sandwiching the pair of vessels between two horizontal copper plates, $25 \times 47 \times 0.056$ cm, electrically connected with one another, but not grounded. The other pair served as the concurrent control and possessed only a cardboard cover. To control for any influence of the different specific sites of the pairs on the table, the application of the copper plates was alternated on successive days between the two pairs of vessels. Any effects of electrical shielding measured as differences from the concurrent control would, therefore, not include consequences of site difference.

Comparably, for the other two pairs of vessels on the table, comprising experimentals and controls for the altered background radiation series, the lead cover was moved on alternate days from one pair to the other. The lead plate comprised a sheet $30 \times 56 \times 2$ cm. The controls received only a cardboard cover.

The lead-plate and electrical-shielding series were continued from June 5 through September 8, 1972.

The effects of the experimental conditions were first recorded day by day as the *difference* in water uptakes between experimentals and their concurrent controls. The mean rates for the two members of each pair were used for this purpose. A review of these differences disclosed that there was an underlying component possessing a good positive correlation between the day by day "responses" to the lead and electric-field environment for those days that the response values did not exceed about $\pm 14\%$ for either one. This is evident from inspection of the scatter-plot of the relationship between the two conditions (Fig. 7). In Figure 7, sixteen out of a total of 67 values are seen to fall beyond the limits. With these values removed $r = +0.57$; $n = 51$.

In view of what appeared to be the existence of a basic positive correlation between the "responses" over a substantial range of values to the two differing experimental treatments, it was arbitrarily decided to consider any day on which the apparent response to either experimental condition equalled or exceeded 20% as the difference between experimental and control as an *aberrant* day. There were eight of these among the 67. It is evident from Figure 7 that these high values were essentially randomly distributed as far as contributing any given relationship between the two experimental series.

It soon became evident that the aberrant days were significantly different from

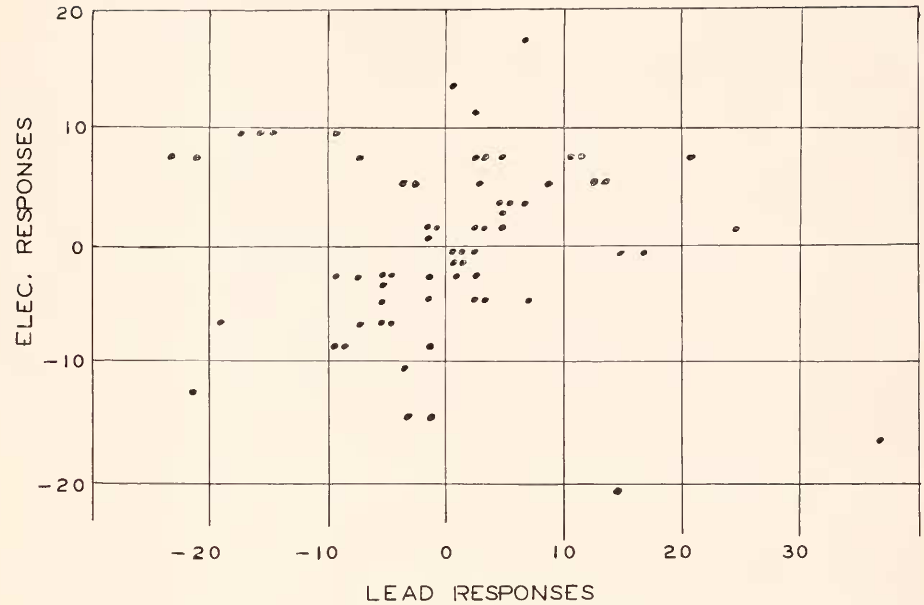

FIGURE 7. Scatterplot of the relationship between concurrent responses (difference between experimentals and controls) to "electrical shielding" and altered background radiation by covering with 2 cm thick lead plates.

the *non-aberrant* ones in also another respect. This was the nature of the interaction between the individual members of the experimental and control pairs when deviations from the daily means of all four pairs on the table were employed. For the aberrant days the coefficient of correlation between members of the pairs (Fig. 8C) was positive, $r = +0.288 \pm 0.10$, $t = 2.7$ ($P < 0.01$) while that between individual members of an experimental pair and an individual member of the control pair (Fig. 8A) was negative, $r = -0.390 \pm 0.093$, $t = 3.8$ ($P < 0.001$) with $N = 84$. On the contrary, for the residual non-aberrant days, the value between members of two different pairs (Fig. 8B) was positive, $r = +0.202 \pm 0.071$, $t = 2.78$ ($P < 0.01$), and that between members of the same pair (Fig. 8D) was negative, $r = -0.348 \pm 0.065$, $t = 5.03$ ($P < 0.001$), with $N = 184$.

These results provide evidence for another apparent property of the phenomenon of interactions between the organisms, namely, an interaction between closely apposed members within pairs may involve not only a biasing of the second of the pair to adopt an *opposite* sign of its correlation with whatever the effective, varying subtle environmental parameter or parameters, but that some environmental conditions may obtain wherein the *intrapair* biasing may be in the direction of the two members adopting the *same* sign.

Geographic and laboratory similarities and differences

Further information concerning characteristics of the environmental variations responsible for the fluctuations in water-uptake and modification of their influences

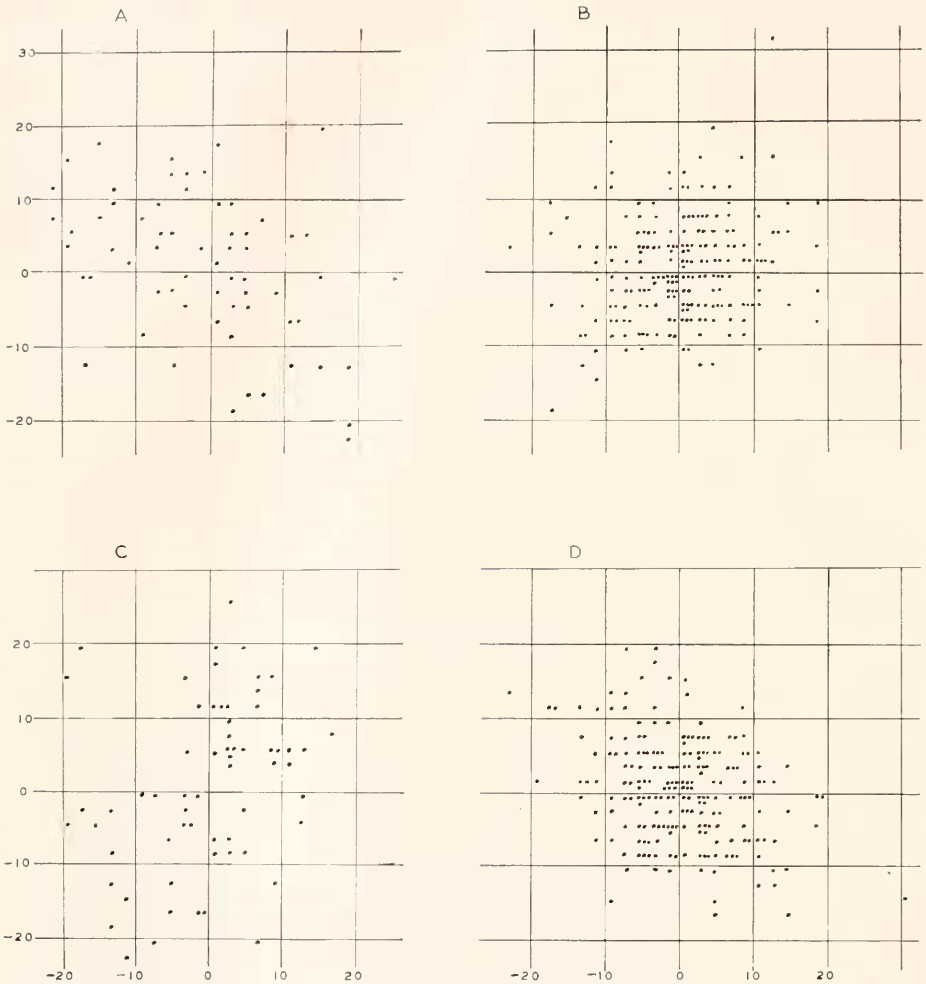

FIGURE 8. Scatterplots of the concurrent relationships between deviations from the daily means for the four electrical shielding and four lead-plate experimental and control pairs of the same day. *Aberrant* days (when response to either shielding or lead cover, exceeded 20) are treated separately from the remaining non-aberrant days. (A) is the relationship for aberrant days between a sample for one member of the experimental with one of the control. (B) is the comparable relationship for the residual non-aberrant days. (C) is, for aberrant days, the relationship between the two members of pairs, and (D) is the same for the non-aberrant days.

by subtle environmental factors came from additional kinds of observations. These involved concurrent studies at widely different geographic points and at different specific sites within the laboratory, including a walk-in, insulated and metal-sheathed, controlled-temperature cabinet ($6\frac{1}{2} \times 7\frac{1}{2} \times 7\frac{1}{2}$ ft).

Figure 9A describes the variation over the period, June 22 through August 4, 1972, of mean water uptake in three rooms in a laboratory suite at the Marine

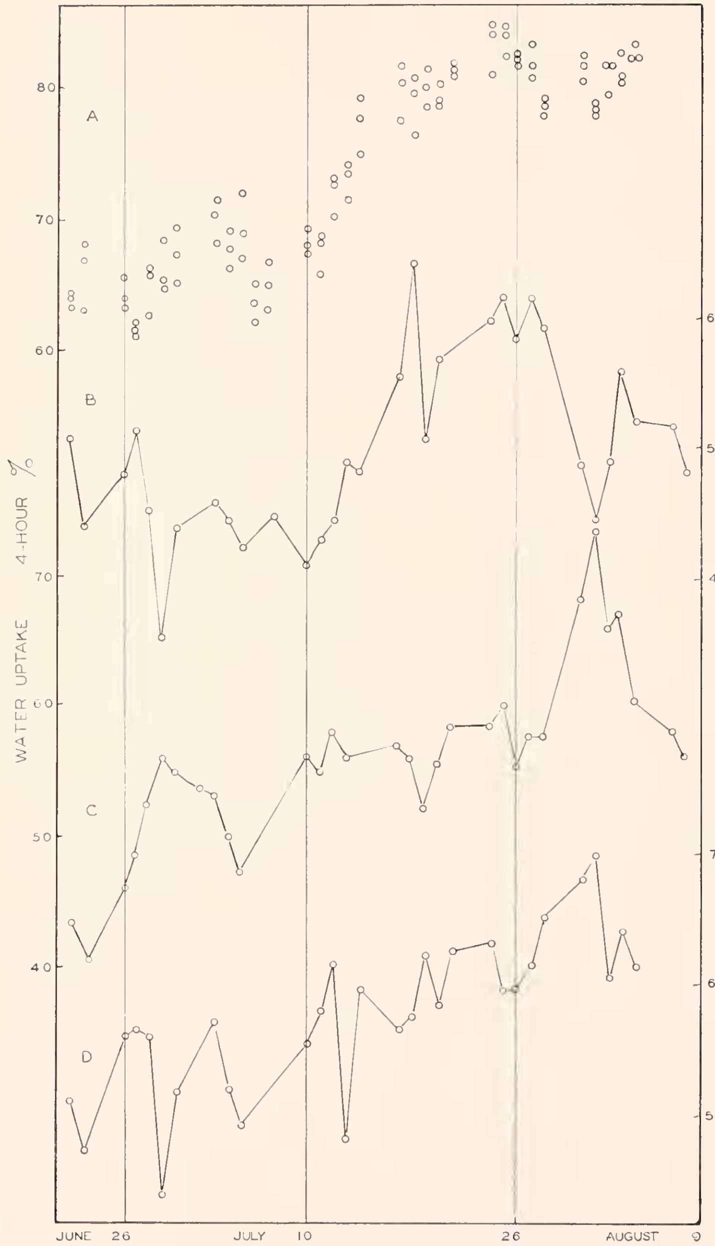

FIGURE 9. Concurrent day by day variation in water-uptake rate (A) in each of three rooms at Woods Hole, Masachusetts, (B) in a walk-in constant temperature cabinet in Evanston, Illinois, (C) on tables in the Evanston laboratory just outside the temperature-controlled cabinet, and (D) in an electromagnetically "disturbed" laboratory site (the electric shielding and lead cover experimental series).

Biological Laboratory, Woods Hole, Massachusetts. The points describe the means for 28 20-bean samples in one room, 32 in a second and 14 in a third for each working day over the period. Figure 9B describes values concurrently obtained by Mr. Jack S. Pierce of Northwestern University as the mean of four samples in the accurately temperature-controlled room in darkness at 23° C in Evanston, Illinois. Figure 9C compares the mean variation for the same period of 21 20-bean samples on wooden table tops in the open laboratory in Evanston in relatively "undisturbed" areas with respect to ambient electromagnetic fields. Figure 9D shows the mean day to day variation for the 8 samples involved in the lead-plate and electrical-shielding experiments on the wooden table in the obviously greatly "disturbed" electromagnetic environment.

It had been noted in the Massachusetts laboratory that a rather abrupt increase in water-uptake rate commenced about July 11, an increase for which there appeared to be no evident explanation in terms of alteration in any obvious environment factor. The level of the mean rate rose from 66% as the average for the interval from June 22 through July 11, to 82% for the period July 17 through August 4. There had thus been a relatively abrupt increase from one general rate level to another, 24% higher.

Essentially the same pattern of rate change had occurred concurrently in Evanston, Illinois, in the temperature-controlled room where, coincidentally, the increase between the same two intervals was also 24%.

For the day to day concurrent variation in the means of the 21 samples involved in the "pairs" and "singles" series described earlier, and in the "triplet" series of experiments referred to earlier (see Fig. 5B) there was, between the same two periods a 22% increase. However, a comparison of the pattern (Fig. 9C) for the total period from June 22 through August 4 suggested that this was quite different from that one for the samples in the controlled temperature room (Fig. 9B) despite the fact that the "singles" and "pairs" were no more than 12 feet away and the "triplet" series no more than 40 feet away in the large laboratory suite just outside the controlled cabinet. Before the July 11 date, the lowest value in the accurately controlled temperature environment (45.7%) occurred on the same day as the highest (55.8%) for those beans outside the controlled room. The variation, both throughout the period of the abrupt rise and after its completion, seemed to possess a relatively strong mirror-imaging relationship. This latter reached its most spectacular proportions when on August 1 one of the two had increased to a peak value of 73% while the other had at the same time dropped to a sharp minimum value of 44.5%.

Meanwhile the eight samples in the electromagnetically disturbed area of the lead and copper shielding series had also exhibited a rise in mean rates between the two intervals from 53.5% to 61.8%, but an increase of only 15.5% (Fig. 9D). An examination of the pattern of water-uptake variation over the whole 44-day period suggested that for about the first two weeks the pattern in the disturbed area paralleled that of the beans in the temperature-controlled room (Fig. 9B), but thereafter appeared to resemble more that of the other, or open laboratory, sample (Fig. 9C).

The apparent general widespread presence and character of the July 12–16 abrupt increase in water uptake rate is again supported by the patterns revealed for the two rotating-platform (6 rpm, CW and CCW) experiments performed in the separate small room about 30 feet away from all other concurrent experimental series (Fig. 5C). In these the July 12–16 rise also occurred. This rise was from 49.0% to 63.6% in the CW series, and from 46.7% to 59.2% for the CCW one. These amounted to rises of 29.8% and 26.8%, respectively.

These observations lend further support for the presumption that any given sample or group of samples of beans are capable of correlating *either positively or negatively* with at least one of the normally uncontrolled but highly influential parameters of the subtle geophysical environment. Furthermore, it is apparent that differences in sign of response may alone account for differences in a fundamentally important biological process, amounting to more than 60% between two concurrent samples at the same local geographic site under what has usually been deemed constant conditions for them. The mean temperature of the air-conditioned, temperature-regulated laboratory was about 22.0° C, that of the accurately temperature-controlled room, 23.0° C.

Finally a comparison was made of the concurrent day by day fluctuations in mean water uptake for eight 20-bean samples being investigated in light and in darkness by Mr. Jack Pierce in the controlled-temperature room at 25° C for the period from September 28 through November 17 (Fig. 10A) with the mean for

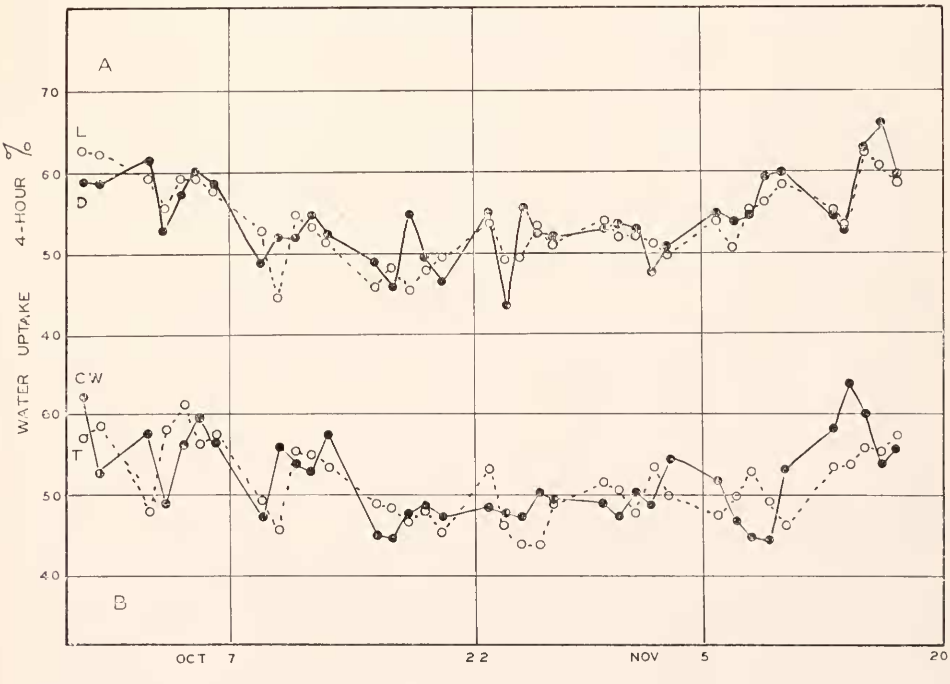

FIGURE 10. Day by day water-uptake variations for (A) (solid line) eight 20-bean samples in a temperature-controlled cabinet at 25° C and in darkness, and (broken line) eight similar samples in the same cabinet but in light. (B) the concurrent variation in the laboratory just outside the cabinet (solid line) for twelve 20-bean samples on a clockwise rotating platform, 2 rpm, and (broken line) nine 20-bean samples arranged as 3 triplet groups.

21 concurrent 20-bean samples in light on a CW rotating (2 rpm) and a stationary platform in the open laboratory (Fig. 10B). Similarities are notable even in relatively minor fluctuations indicating a continuing day by day paralleling influence of subtle pervasive parameters of the atmosphere in inducing fluctuations in such an elementary phenomenon as water uptake by dry seeds. This comparison confirmed also that a mirror-imaging capacity and tendency also commonly occurs as is particularly evident for the last few November values.

Discussion

A high degree of responsiveness to subtle parameters of the geophysical environment has been repeatedly described over the past century but especially over the past two decades for many kinds of organisms. Substantial variations in such phenomena as spontaneous activity, rates of oxidative metabolism in animals and plants, and response to light have been reported to be correlated with solar and lunar related periods even when the organisms are held in constant conditions (Lang, 1965; Brown, Hastings and Palmer, 1970). This indicates that these creatures are able to reflect relatively minute differences in pervasive correlates of these overt environmental fluctuations, correlates that are able to penetrate into experimental environments in which every obvious factor is held in an unvarying state. The current studies confirm and emphasize this state of affairs and indicate a surprisingly large magnitude of their potential effects.

The relevant variations in the external environment appear to be geoelectromagnetic fluctuations. These latter would be expected to be of the same general order of magnitude as those electromagnetic fields generated by the organisms themselves and in whose mutual fields organisms placed in close proximity to one another are found. The field of the organisms might be expected to effect a modification of the natural ambient field comparable in degree to weather-associated and geophysical-period-related alterations.

The biological fluctuations induced by subtle environmental changes, in view of their relatively large ranges, would be predicted to elicit compensatory reactions through the servomechanisms normally operating in homeostatic regulation (Brown, 1972). The activities of these mechanisms would superimpose their own modification upon any immediate responses of the biological systems to the physical factors.

The most plausible and consistent hypothesis to account for the remarkable positive and negative correlations as well as the absences of correlations that have been described in the current study seems to be that any bean sample is potentially able to adopt either a positively or a negatively correlating relationship with whatever the effective, steadily varying subtle geophysical environmental parameter which is involved. Abrupt, inexplicable apparent sign changes with time have been noted and found very frustrating over the years by many investigators who have attempted to discover correlations of diverse biological phenomena in controlled, presumably constant, conditions with geophysical parameters including barometric pressure, atmospheric temperature, background radiation, and primary cosmic radiation (Brown, 1959, 1960, 1968; Brown, Webb and Bennett, 1958). The last one was probably a consequence of response to geomagnetic variation. Sign-changing correlation of rat activity with sunspot number has also been noted (unpublished records from earlier studies by one of us, F. A. B)

If this sign-changing capacity exists for an organism and, in this instance, for a small cluster of beans then it would appear from the present observations that each of the members of the paired samples of beans, even when present in separate glass or plastic containers, can somehow be influenced by a very weak electromagnetic field produced by the other. By some means, the adoption of a "positive" state in one member of a pair must under some circumstances bias the other member of the pair within their mutual field to adopt the "negative" state. Correlating with opposite sign with the still uncontrolled effective parameter or parameters of the fluctuating pervasive physical environment, the negative correlations over substantial ranges of rates would be thereby effected. Variations in the physical environment calling forth greater organismic response than within this range, would appear often to overwhelm the influence from the mutual association between the members of the pair and under normal conditions lead to a superimposed larger-range positive correlation.

In the instance of the beans on the rotating platform in the preliminary study, such a hypothesis would account for the results if the beans in one bowl biased the sign of the beans in the two closer other bowls toward possessing a sign opposite from itself. Thereupon the beans of the diagonally-opposite bowls would be expected to be, in turn, biased to the opposite sign of its two closest bowl partners. The members of one diagonal couple would be predicted to be mutually "positive," and the other mutually "negative," and a good positive correlation could be under these circumstances the product of relating the diagonal pairs, just as was observed. Under other environmental circumstances, with biasing of the two members of closely apposed pairs to the same sign, the members of a second pair more distant but still within effective range might be biased jointly to the opposite sign as in the lead plate and electrical field shielding series.

It seemed less plausible that the two members of a pair of bean trays located within 7 to 35 cm of one another would be subjected to sufficiently different fields derived from their physical environment to tip the two to oppositely correlating signs as consistently as has been observed. And too, in the rotated groups of beans, all four trays on a given table in effect, over time, occupied the same detailed laboratory site.

It is also of interest in the light of the totality of the results to reexamine, for instance, Figure 1, Figure 3C and Figure 4B and others. In these, the correlations, positive or negative, have been significantly diminished by presence of values which seemed to suggest simultaneous but weaker tendency for correlation with the opposite sign.

The rotating magnetic field is postulated to interfere completely with whatever the mechanism of interaction among the bean samples and yield a state of affairs similar to that observed when bean samples are separated from one another by distances of half a meter or more. Comparable low frequency, relatively weak, rotating magnetic fields have been reported to alter behavioral development in rats (Persinger, 1969; Persinger and Foster, 1970).

One of the interesting aspects of these findings pertains to the current views as to general nature of processes involved during the first few hours of water absorption by a seed. Only physical processes have been considered to be significant over this period. The results of this investigation, on the other hand, indicate that biological factors probably play a substantial role. Interaction between organisms and organisms and their ambient environment through electromagnetic fields have both been postulated by Presman (1970) to occur. While it is admittedly difficult to credit that biological interactions of this nature can occur, it is perhaps even more difficult to imagine how such negative correlations could be generated in terms solely of interactions between two isolated simple physical systems. *Positive* correlations could, obviously, be readily explicable and indeed have been predicted, but not *negative* ones. It seems reasonable to postulate, therefore, that the embryo within the seed possesses the capacity to regulate within limits the rate of water uptake within that seed, and even in adjacent seeds, other factors equal. It is significant in this connection that a circadian rhythm has recently (Bryant, 1972) been reported for gas uptake in onion seeds.

It is suggestive that a maximum in rate of water absorption during the nine months of this study occurred in late July and August (Fig. 5), and a broad minimum seemed to be occurring in November (Fig. 10). This phenomenon, therefore, appears to involve subtle environmental parameters in common with those responsible for other reported persistent annual variations (see Brown, Hastings and Palmer, 1970), which similarly pass through their maximum and minimum at these same times of year.

It seems probable that the general phenomenon of organismic interaction by very weak electromagnetic fields that has been disclosed in this study is widespread among living things, if not universal. If this is true it carries great implications for all of regulatory biology. It is evident that precise reproducibility of results in time, at least when one is dealing at levels of integrated and functional biological systems will be unlikely. The quantitative, and often even qualitative, character of results may be in part determined by uncontrolled factors even as subtle as the proximity of other individuals of the same, or possibly even different, species as well as by time within the now widely acknowledged relatively predictable, solar and lunar circadian cycles, and monthly and annual ones. Less predictable variations associated with movements of weather systems, and fluctuations in solar activity may also be expected to impose *significant* influences.

And not least, the existence of the phenomenon indicates that we are operating within the range of a biological "uncertainty principle." There is now clear reason to presume that the uses of modern methods, facilities and equipment for making precise measurement of diverse parameters in living systems exert of themselves an influence upon the system being measured, an influence effected by the invariable and characteristic weak accompanying alterations in electromagnetic fields produced by these. Biological processes will reflect in their measured values the methods and conditions under which the measurements are made, and the differences may be substantial.

The relatively large range in variation which appears to be associated with the sign of biological correlation with subtle geophysical factors suggests potential practical roles in the health sciences. Biometeorology with its medical aspects includes a significant influence of weather correlates on living systems. If these influences may be in either of two directions, as evidence now indicates, and based upon positive and negative correlating relationships, one of these signs can be expected for any given time and circumstances to be deleterious relative to the other. Increased understanding of the factors determining correlation sign together with discovery of the means to regulate living systems at will in this respect could quite conceivably provide a basis by which clinical crisis intervals might be alleviated, or bypassed with decreased stress.

Indeed, in this last connection one can speculate that the reversible correlating sign and its modifications by interaction between organisms or groups is biologically adaptive. Viewing the need for maintenance of a species as transcending survival of single individuals or single groups, the species is steadily provided with two possibilities for survival, + and − states, in its response to the natural fluctuations in its geoelectromagnetic environment.

Summary

1. The mean rate of water uptake by beans during the first four hours of their submergence in water varies substantially from day to day, even when in presumed "constant" conditions.

2. The variations in rate in independent samples at different laboratory sites and even at widely different geographic ones may show a strong positive correlation not explicable in terms of variations in any obvious factor.

3. Superimposed on a major positively correlating state, is a secondary, shorter-period fluctuation wherein the correlation between different groups of samples may exhibit either a positive or a negative correlation.

4. Groups of organisms in closely juxtaposed vessels may bias one another to adopt *opposite* sign of correlation under some conditions and the *same* sign under others.

5. This interorganismic biasing may be prevented by having the paired vessels in the very weak field of a very slowly rotating (2 rpm, CW) horizontal bar magnet, or by separating the vessels by 70 cm or more. In either case, the separate vessels then appear to correlate positively and negatively with about equal frequency, indicating independence of one another.

6. Pairs of vessels upon rotating tables at 6 rpm are modified in their interactions in manners dependent upon direction of rotation. Other factors equal, CW rotation appears to favor positive correlation between members of pairs, CCW rotation favors negative correlation.

7. Platform rotation even at the very slow rate of one revolution a day (CW) appears to effect an alteration in the character of the interaction between closely apposed bean samples.

8. Partial electrical shielding by copper plates and experimental alteration of the ambient background radiation by a lead plate modify the rate of water uptake by beans.

9. The interactions between organisms and organisms and their subtle physical environment as they determine positively and negatively correlating states are able to yield biological differences, even on the order of a 2-fold range, concurrently and under the same conditions of all obvious environmental factors.

10. Parallel and concurrent variations in bean samples as widely separated as Woods Hole, Massachusetts and Evanston, Illinois, suggest wide geographic scope of at least one of the major effective subtle parameters.

11. The nature of the phenomenon for beans is of such character that it appears probable that the living embryo within the dried seed possesses the capacity to regulate to a substantial degree the rate of water absorption by the seed upon its submergence.

12. On the presumption that the phenomenon that has been treated herein is a universal biological one, the implications of these findings are great. They relate to (a) reproducibility of experimental results, (b) biological influence of the weak fields of diverse facilities and equipment employed for measurement of biological phenomena, (c) additional and subtle means through which man's alteration of his environment may influence living creatures and (d) potential practical applications of knowledge of the subject for the health sciences.

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